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SONAR DOPPLER DISCRIMINATION IN HIGH NOISE ENVIRONMENTS

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13. ABSTRACT

This experiment was concerned with the ability of anti-Submarine Warfare helicopter-borne sonarmen to perform doppler discrimination in the high background noise existing aboard rotary winged aircraft. Performance on a frequency discrimination task was measured under conditions in which the background noise was varied in intensity up to levels approaching those found aboard helicopters. The level of the signal was also varied such that under some conditions the signal was only slightly audible above the noise while under some conditions the signals were clearly audible. It was found that the intensity of the noise was not, of itself, related to the acuity of frequency discrimination. Rather, the differences between the signal level and noise level was most directly related to pitch discrimination performance. It was concluded that, if the signal level could be maintained well above the background noise level, doppler discrimination would not be seriously impaired.

14. KEY WORDS	LINK A		LINK B		LINK C	
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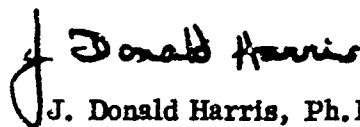SONAR DOPPLER DISCRIMINATION IN HIGH NOISE ENVIRONMENTS

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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
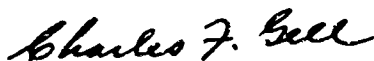NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 651

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SUMMARY PAGE

THE PROBLEM

To determine whether or not the high noise levels that exist in Anti-Submarine Warfare (ASW) helicopters interfere with the ability of sonar operators to perform doppler discriminations.

FINDINGS

For noise spectrum levels up to 75.5 dB, and for noise centered about the system transmit frequency, no serious deterioration in doppler discrimination will occur, provided signal levels are maintained at a level at least 15 dB above the detection level of the signal in the background noise. For lesser signal differentials doppler discrimination is impaired, with the degree of deterioration being inversely related to signal differential and directly related to noise level.

APPLICATIONS

These findings contribute to the specification of design criteria for ASW helicopter sonar work spaces and for sonarman head gear.

ABSTRACT

Navy personnel who were young, inexperienced listeners performed a pitch discrimination task in quiet, and in noise. The noise consisted of a 600 to 2400 Hertz band of white noise having band spectrum levels of from 58.5 to 75.5 dB re 20 $\mu N/m^2$. Pitch discrimination was measured for sensation levels of 5, 10, and 15 dB. Pitch discrimination was found to be relatively unaffected by noise level but greatly dependent on sensation level. A significant interaction between noise level and sensation level was observed.

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SONAR DOPPLER DISCRIMINATION IN HIGH NOISE ENVIRONMENTS

INTRODUCTION

On 15 August 1967, a conference on noise levels in ASW helicopters was held at the Munitions Building in Washington, D. C. Specifically, the conference was concerned with defining the acoustic attenuation properties of flight helmets which would permit airborne sonarmen to function optimally.

The meeting was called by Air Systems Command, Code 53303. Among the organizations represented were Air Systems Command, Naval Air Development Center, Naval Air Test Center, Naval Underseas Warfare Center, and Naval Aero-Medical Institute, Pensacola. Naval Submarine Medical Research Laboratory representation was requested through the Naval Underwater Sound Laboratory, now the New London Laboratory of the Naval Underwater Systems Center.

A number of attendees presented data on noise levels in helicopters and on the effects of noise levels on the hearing of sonarmen. It was shown that airborne sonar operators suffer temporary threshold shifts during missions. The high background noise levels in which airborne sonar operators work necessitates listening at very high noise levels. The types of discriminations required in sonar operation (intensity, doppler, etc.) have not been systematically explored at very high noise levels. Such work as has been done has not considered noise spectrum levels beyond about 45 decibels (dB) above 20 micro-Newtons per square meter ($\mu N/m^2$).

Typically, airborne sonarmen are equipped with a protective helmet into which is incorporated a circumaural noise barrier which in turn encloses an earphone. The attenuation provided by such devices is limited to about 45 to 65 dB by the minimum audible body conduction level[1]. Consequently, further attenuation of the helicopter noise which gets into the sonarman's ear must be gained by isolating the sonarman from the aircraft. Such isolation has a weight cost which must be kept within well defined limits in order that the performance of the aircraft is not impaired. It is essential, then, that the degree of isolation required be very precisely determined.

Subsequent to the conference, a number of inquiries were received informally from NADC, Johnsville, and the New London Laboratory of the Naval Underwater Systems Center for further information on pitch (doppler) discrimination under high noise levels. Accordingly, a search of the literature was initiated which yielded but a single relevant report[2].

Jesteadt and Bilger[2] measured differential frequency discrimination (DF) at 1000 Hertz (Hz) in quiet and in the presence of a 700 to 1400 Hz band of noise at octave band Sound Pressure Levels (SPLs) of 60, 80, and 100 dB re 20 $\mu N/m^2$. Under all noise conditions and in the quiet condition the sensation level (SL) of the signal was 15 dB or less. That is, the level of 1000 Hz tone was not more than 15 dB above the

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level at which the tone could be just recognized in the noise background. The DFs were obtained by means of a tracking task in which the subject controlled the extent of warble in the 1000 Hz tone. As had earlier studies using lower noise spectrum levels[3.7], Jesteadt and Bilger found that regardless of noise level DF became smaller as SL increased. However, unlike the earlier studies they found that the higher noise levels had a detrimental effect on DF, especially at the lower SL values. Their findings are presented in Figures 1 and 2. The data in Figure 1 were obtained from inexperienced observers. Data in Figure 2 were obtained from three sophisticated observers. Jesteadt and Bilger called attention to differences in the procedures used in their study and in previous research and suggested that discrimination between pairs of steady pure tones, such as were used in the earlier studies, and the detect n of frequency modulation

Fig. 2. *Mean DF as a Function of Sensation Level for Quiet and Three Noise Levels. (Each point represents two trials for each of three sophisticated observers. From Jesteadt and Bilger[2]).*

may be quantitatively different tasks. Such task differences may underlie the lack of agreement between Jesteadt and Bilger's work and that of earlier investigations. In order to check this possibility the present experiment was executed, utilizing a pitch memory task.

METHOD

Subjects. Forty-five male enlisted men were selected at random from among three groups of men who had passed the routine screening audiometric examination administered to Submarine School candidates. Subjects
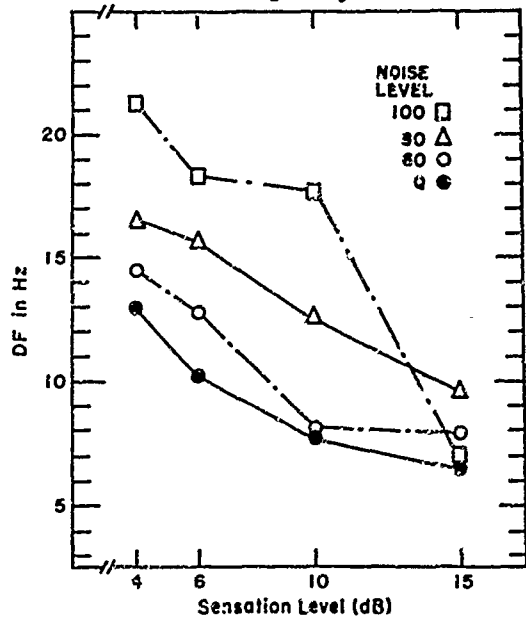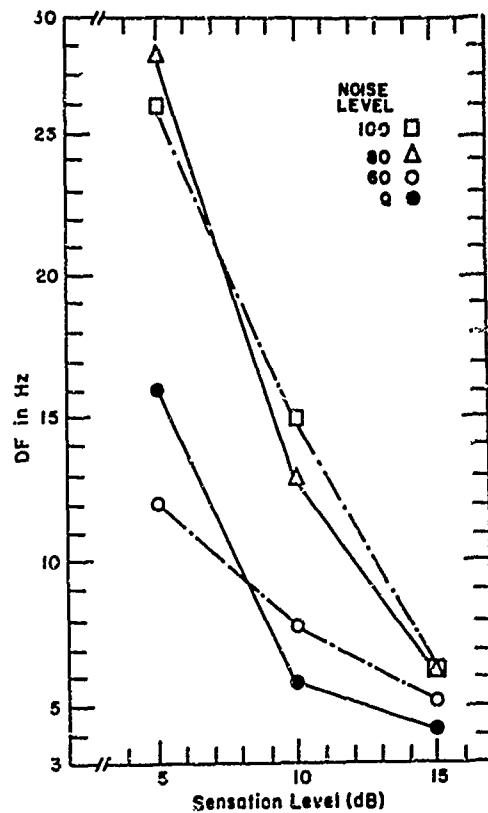

Fig. 1. *Mean DF as a Function of Sensation Level for Quiet and Three Noise Levels. (Each point represents four trials for each of five naive observers. From Jesteadt and Bilger[2]).*

were not screened further. The typical subject, however, was an apprentice seaman with no sonar experience or other job experience requiring listening and the sample may therefore be considered as having consisted of inexperienced observers.

Apparatus. A tape recorded pitch memory test was used as a measure of pitch discrimination. Each of the 100 items of this test consisted of two 500 millisecond (msec) tones separated by an interval of 500 msec and followed by a 4.5 second response period. The second of the two tones of each item was either higher or lower in frequency than the first tone. The distribution of frequency differences (DF) for the tests is shown in Table I. The frequency of the standard (first) tone was 1150 Hertz (Hz). The test was recorded on one channel of a 1/4" tape (Channel A). The other channel (Channel B) contained bursts of noise which roughly coincided with the items. That is, the noise came on just prior to the onset of the standard tone and went off just following the offset of the second (comparison) tone. During the response period the noise remained of. The noise was a two-octave band (600 to 2400 Hertz) of white noise.

The test was presented with the apparatus sketched in Figure 3. The tape was played on a PR-10 tape deck with the outputs of the two channels (A and B) fed independently to Hewlett Packard 350-D decade attenuators. Attenuator A controlled the level of the test items and Attenuator B controlled the level of the noise bursts. The tones and noise were then mixed and led to an Altec Model 1569A amplifier which

Table I. Composition of Pitch Memory Test.

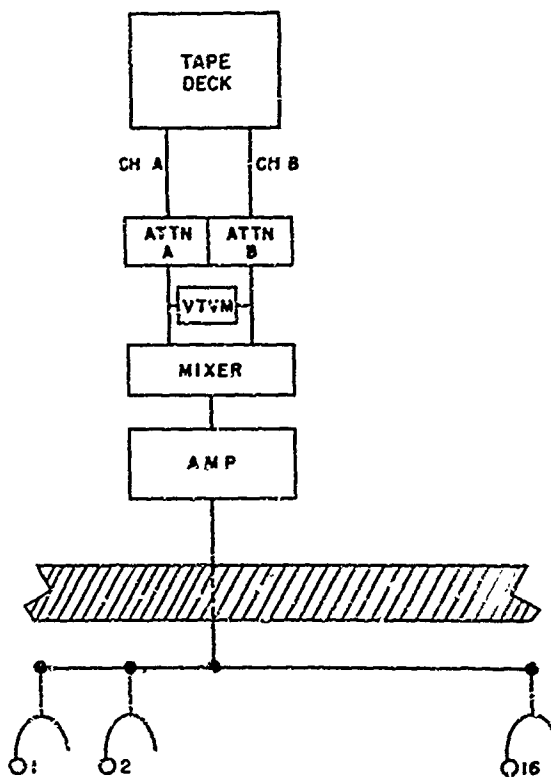| ITEMS	FREQUENCY DIFFERENTIAL IN HERTZ
1-30	25
31-60	20
61-80	15
81-90	10
91-100	5

Fig. 3. Schematic for Experimental Apparatus. (See text)

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drove 16 matched PDR-10 earphones in a sound-proofed group testing room. A Ballatine Model 643 vacuum tube voltmeter was used to monitor the signal and noise voltage levels. The subjects recorded their responses on an answer sheet by crossing out an H or L for each item as appropriate.

Procedure. The subjects were tested in three groups with 15, 16, and 14 men in each group. As a partial control for possible order effects, the sequence in which the experimental conditions were presented was reversed for group 2. Otherwise the procedure for groups 1 and 2 were as follows:

The men were seated, the purpose of the experiment was explained, and the instructions for the test were read. Then, the pitch memory test was presented with no noise (Channel B at maximum attenuation). Next, Channel B was set to produce a noise level of 100 dB Sound Pressure Level (SPL) and the tape replayed. The subjects were instructed to raise their hands if they could hear the tones on each item. Channel A was then adjusted until about one half of the men in the group could hear the tones. This level was designated as the group recognition differential or sensation level of 0 dB (SL_0). Then, varying the level of Channel A to produce sensation levels of 5, 10 and 15 dB (SL_5, SL_{10}, and SL_{15}, respectively), three successive presentations of the last sixty items of the test were made. Then the noise level was adjusted to 90 dB SPL and Channel A reduced by 20 dB to yield an SL_5. Three presentations (SL_5, SL_{10}, SL_{15}) of the

last 60 items of the test were then made at the 90 dB noise level. Between presentations, answer sheets were collected and fresh ones issued while the tape was reset. This process provided a three-to four-minute break between conditions during which time the subjects removed their headsets. Total running time for the preliminary test and the six noise level conditions was about 70 minutes.

The third group was run under conditions in which the noise level was first set at 98 dB and then 108 dB SPL. Under the 108 dB noise condition, sensation levels of 5, 10, and 15 dB were used. For the 98 dB noise conditions the settings used for attenuator A were those appropriate for sensation levels of 15, 20, and 25 dB. In terms of the SPL of the signal, these settings produced the same three signal intensity levels as were used for the 108 dB noise level.

The pitch test was scored as four subtests: That is, items 41-60 were treated as a test of 20 Hz discrimination, items 61-80 as a test of 15 Hz discrimination, items 81-90 for 10 Hz, and items 91-100 for 5 Hz. Each subject's score for each subtest was one-tenth of the percentage of items correct. The subject's pitch discrimination score was the sum of the scores for the subtests for each experimental condition. These scores were used for all statistical analyses. The mean of scores for each subtest was then plotted as a function of DF and the 75% correct frequency discrimination point interpolated.

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RESULTS AND DISCUSSION

The pitch discrimination scores for groups 1 and 2 were combined and were subjected to a Treatments by Treatments by Subjects analysis of variance, the treatments being noise level and sensation level. The results of the analysis are shown in Table II. The effect of sensation level on pitch discrimination scores was highly significant (P<.001) but the effect of noise level was negligible (P>.10).

Table II. Summary of Analysis of Variance of Frequency Discrimination Scores for Groups 1 and 2 Combined (n = 31)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F	p
SL*	1772.3897	2	886.1948	63.2016	<.001
Noise Level	38.8440	1	38.8440	2.0450	>.1
Interaction	282.3899	2	141.1949	11.6080	<.005
Error 1	841.3025	60	14.0217		
Error 2	569.8227	30	18.9940		
Error 3	729.8131	60	12.1635		
Subjects	4986.9462	30			
TOTAL	9221.5081	185			

Error 1 is the error term for SL; Error 2 for noise level; and Error 3 for SL by noise level interaction.

*Sensation Level

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A significant interaction between SL and noise level did appear and is graphed in Figure 4. For SL_5 conditions, performance declined as the noise level was increased from 90 to 100 dB SPL. For the SL_{10} conditions, a similar but more gradual decrement occurred. For the SL_{15} conditions, however, performance was apparently enhanced under the higher noise level.
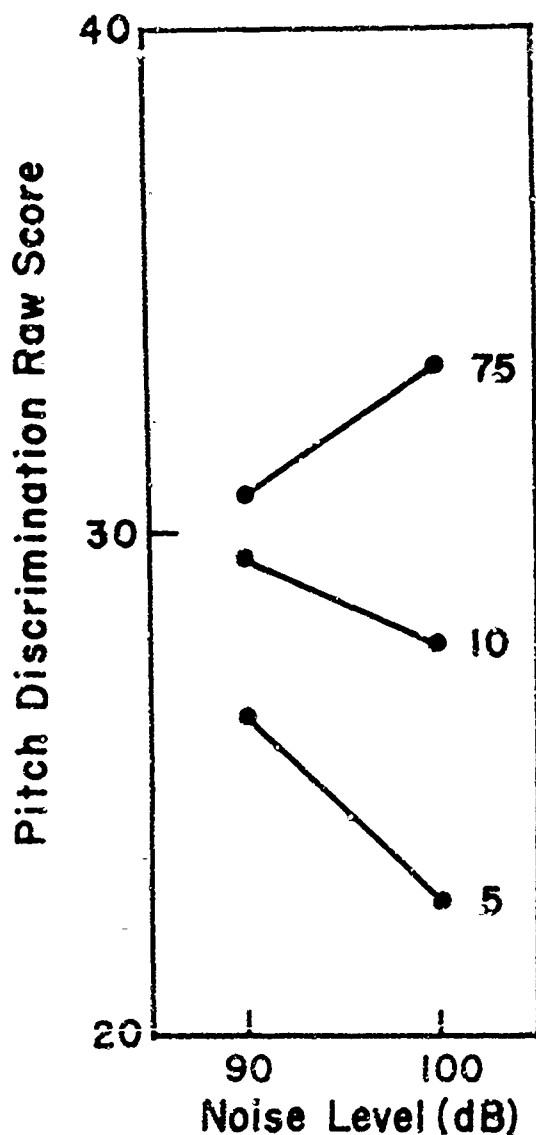

Fig. 4. *Interaction of Sensation Level and Noise Level.*

The data for group 3 were also subjected to analysis of variance with the results shown in Table III. In this analysis the treatments are noise level and signal level both of which produced significant differences in pitch discrimination scores ($P < .001$). No significant interaction between noise level and signal level appeared ($P > .1$).

The group 3 mean scores are presented in Table IV A. Although the differences in mean pitch discrimination scores for the two noise levels and three signal levels are quite obvious these same results, when listed as in Table IV B, are seen to be easily attributed to the varying SL. It is interesting to note that as SL increases up to SL_{25} for the 98 dB noise level the pitch discrimination scores continue to increase. Performance at SL_{20} and SL_{25} does not differ significantly from the mean pitch discrimination score for this group in quiet.

The mean pitch discrimination scores of groups 1 and 2 under all conditions are listed in Table V along with the mean scores for group 3 under the 108 dB noise level. Since these groups were drawn from the same subject pool (Submarine School Candidates) direct comparisons among the effects of the experimental variables are justified. It has already been shown that the mean scores for noise levels 90 and 100 dB are not significantly different. Student's t for independent means was computed to compare the effects of 108 dB noise with 100 dB noise and with 90 dB noise. The computed t values were .387 and 1.068, respectively, neither being significant. Since the means are so

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Table III. Summary of Analysis of Variance of Frequency Discrimination
Scores for Group 3 (n = 14)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F	p
Signal Level	903.2916	2	451.6458	24.7194	< .001
Noise Level	550.2975	1	550.2975	30.7095	< .001
Interaction	25.7916	2	12.8958	1.6103	> .1
Error 1	475.0416	26	18.2708		
Error 2	232.9524	13	17.9194		
Error 3	208.2082	26	8.0080		
Subjects	982.1190	13			
TOTAL	3377.7023	83			

Error 1 is the error term for signal level, Error 2 for noise level, Error 3 for
the signal level by noise level interaction.

Table IV A

Signal level	NOISE LEVEL		
	98	108	$\overline{X}$
88	29.29	24.14	26.71
93	35.79	29.32	32.55
98	36.29	32.54	34.41
$\overline{X}$	33.79	28.67	31.23

obviously close this result may be interpreted as indicating that the respective variances are also similar. The effect of SL is similar at all noise levels. The interaction of SL and noise level noted for noise levels of 90 and 100 dB seems to exist through the 108 dB noise level, but it is somewhat attenuated.

The 75 percent correct frequency discrimination points (DF .75) for each noise level are plotted as a function of

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Table IV B

SL	NOISE LEVEL	
	98	108
5		24.14
10		29.32
15	29.29	32.54*
20	35.79	
25	36.29	
$\overline{X}$	33.79	28.67

*Difference between means for
SL_{15} is significant, $(P<.05)$
Mean pre-exposure score for
group 3 was 26.96.

SL in Figure 5. These results may be
compared with Jesteadt and Bilger's
data in Figure 1 and 2. Very good
correspondence exists between the data
for the inexperienced subjects shown in
Figures 1 and 5. The interaction effect
between noise level and SL noted for
the raw scores of groups 1 and 2 com-
bined is reflected in the displacement of
DF .75 for the 90 dB noise level for
SL_{15} in Figure 5.

The interaction is also plotted in
Figure 6 which shows DF .75 as a func-
tion of noise level for the various SL's.
As did the raw scores in Figure 4,
Figure 6 strongly suggests that as noise
level increases for fixed but low levels

Table V

Mean pitch discrimination scores for three sensation levels
at three noise levels.

NOISE LEVEL	SL5	SL10	SL15	$\overline{X}1$
90	26.26	29.54	30.84	28.88
100	22.73	27.95	33.23	27.97
108	24.33	29.32	32.54	28.67
$\overline{X}$ SL	24.44	28.94	32.20	

$\overline{X}_1$ are the means for noise levels across sensation levels

$\overline{X}_{SL}$ are the means for sensation levels across noise levels

NOTE: The mean pre-exposure pitch discrimination score over all
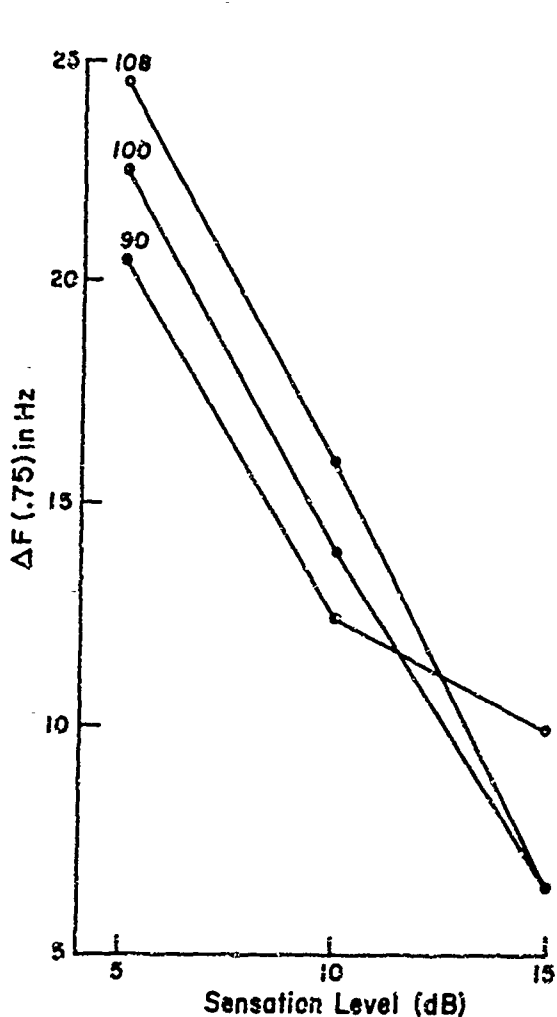subjects was 36.1

Fig. 5. *Frequency Discrimination as a Function of Sensation Level for Three Noise Levels.*
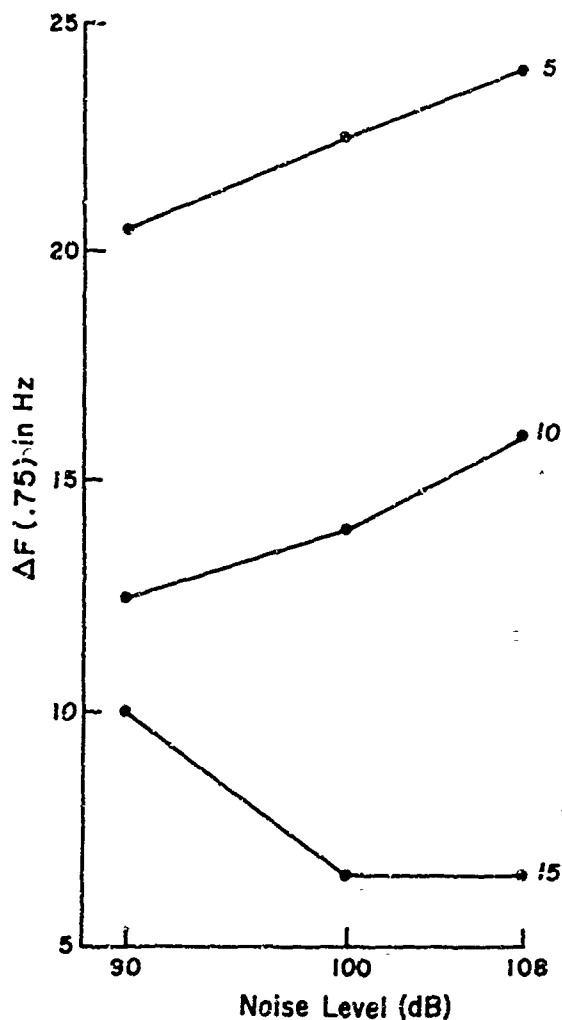

Fig. 6. *Frequency Discrimination as a Function of Noise Level for Three Sensation Levels.*

of SL, frequency discrimination deteriorates. However, as the signal level rises above the noise such that SL approximates 15 dB, pitch discrimination becomes relatively independent of noise level – at least up to noise band levels of 108 dB. The data in Table IV B suggests that above SL_{15} performance becomes a function of SL of signal level. In a no-noise (control) condition, Jesteadt and Bilger found DF to improve with increasing signal levels up to 96 dB SPL.

The Jesteadt and Bilger data of Figures 1 and 2 are also replotted to show DF as a function of noise level for the various SLs used in their study.

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These data, shown in Figure 7, exhibit a
similar interactive effect to that shown
in Figure 6. That is, for low SLs the
regression of DF SL noise level is quite
marked, but for SL_{15}, DF is relatively
independent of noise level. This pro-
gression seems to hold for both inex-
perienced and sophisticated observers.
A similar effect appeared in Henning's
results[7] for performance on a 7 Hz
discrimination task (Standard frequency
of 1000 Hz), and is shown in Figure 8.
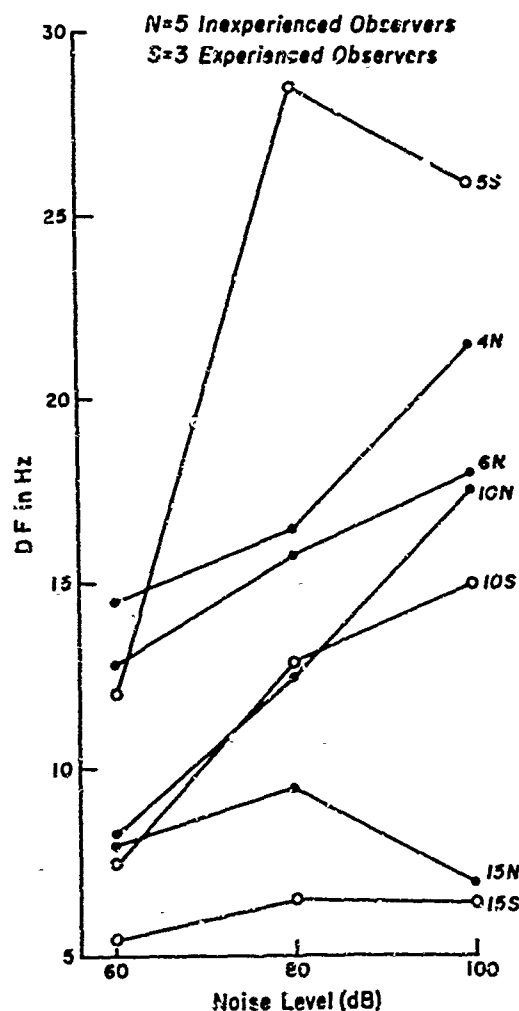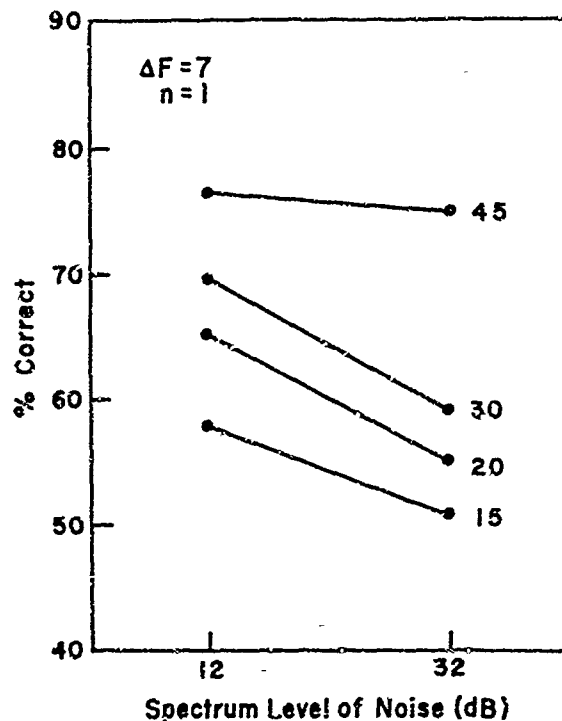These data are for a single observer

Fig. 8. Percent Correct Responses on a 7-Hertz Discrimina-
tion Task. (Standard Frequency was 1000 Hz. Data
are for a single observer. Replotted from Henning[7]).

and should be regarded with caution
especially in view of the fact that
Henning made no mention of these dif-
ferences concluding only that noise
level per se had little effect on per-
formance. Note also that in the current
experiment, 75 percent correct re-
sponses were being made at 6 to 10 Hz
frequency separation for an SL of 15 dB.
Nevertheless, the trend exhibited in
Henning's data is similar to that shown
in Figure 4 for pitch discrimination
raw scores and in Figure 6 for DF.
However, in Henning's data, the
transition from noise level dependence
to independence from noise level
appeared between SLs of 30 and 45 dB.
This discrepancy may be due to sampl-
ing errors or individual differences.

Harris[4], using noise levels sufficient
to mask 800 Hz tones having sensation

Fig. 7. Jesteadt and Bilger Data Replotted to Show Frequency
Discrimination as a Function of Noise Level for Various
Sensation Levels.

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levels of 25 and 45 dB, found that discriminability did not change for the worse when noise level was increased by 20 dB for SLs of 5 and 10 dB. Brandt and Small[6], using a wider range of SL but noise levels similar to those of Harris, also concluded that pitch discrimination at 1000 Hz varied only as a function of SL. Loudness and overall sound pressure level per se had little effect on DF. The spectrum levels of masking noise used by Henning, Brandt and Small, and Harris, are considerably lower than the levels used in this study and overlap only the lowest level used by Jesteadt and Bilger. Perhaps these differences in masking level account for the lack of agreement. That is, it may be that the interaction between SL and noise level occurs only at high noise levels.

Although the findings of this study are defensible, there are a number of points which must be raised by way of qualification. First, the test of pitch memory used is not of sufficient difficulty or precision to permit drawing a psychometric function for each individual subject under any but the lowest SL conditions. Thus, the percentage of items correct on each subtest was summed across subtests to arrive at the raw "pitch discrimination" score for each subject. Although such scores are certainly correlated with pitch discrimination in terms of DF .75, it is very probable that the correlation is not perfect. Since statistical analyses could-be performed only on raw pitch discrimination scores, it is not strictly legitimate to draw conclusions about DF .75. Second, the method used to determine SL_0 implies that any SL is but an average SL. For example, at SL_5,

some subjects were operating at an SL perhaps approaching SL_{10} while others may have been operating at close to SL_0. Such differences would detract from the precision of the experiment. Third, calibration data revealed that the signal levels were somewhat weaker at SL_0 than one would predict on the basis of the spectrum levels used[8]. Specifically, for the 90 and 100 dB band levels, the spectrum levels were 57.5 and 67.5, respectively. For these spectrum levels the signal level at SL_0 should have been about 75.5 and 85.5 dB rather than the 72 and 82 dB observed. An experiment using experienced observers on an individual basis is currently being conducted which will be free of the above-mentioned shortcomings.

With the foregoing reservations in mind, it may be concluded that, within the limits of the conditions of this experiment, pitch discrimination performance is not affected by noise level per se. Rather, performance seems to be more directly related to sensation level. However, an interaction between sensation level and noise level was observed. Specifically, for low values of 'SL, pitch discrimination scores vary inversely with noise level. At about SL_{15}, pitch discrimination becomes independent of noise level, becoming rather a simple function of SL or, perhaps, signal level.

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